



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification <sup>6</sup> : <b>C12Q 1/18, 1/06, 1/48</b></p>	<b>A1</b>	<p>(11) International Publication Number: <b>WO 99/37799</b></p> <p>(43) International Publication Date: <b>29 July 1999 (29.07.99)</b></p>																								
<div style="display: flex; justify-content: space-between;"> <div style="width: 48%;"> <p>(21) International Application Number: <b>PCT/GB99/00089</b></p> <p>(22) International Filing Date: <b>12 January 1999 (12.01.99)</b></p> <p>(30) Priority Data:</p> <table style="width: 100%; border: none;"> <tr> <td style="width: 33%;">9801126.5</td> <td style="width: 33%;">21 January 1998 (21.01.98)</td> <td style="width: 33%;">GB</td> </tr> <tr> <td>9816993.1</td> <td>6 August 1998 (06.08.98)</td> <td>GB</td> </tr> </table> <p>(71) Applicant (for all designated States except US): <b>THE SECRETARY OF STATE FOR DEFENCE [GB/GB]; Defence Evaluation and Research Agency, Ively Road, Farnborough, Hampshire GU14 0LX (GB).</b></p> <p>(72) Inventors; and</p> <p>(75) Inventors/Applicants (for US only): <b>MURPHY, Melanie, Jane [GB/GB]; DERA Porton Down, Defence Evaluation and Research Agency, Salisbury, Wiltshire SP4 0JQ (GB). PRICE, Rachel, Louise [GB/GB]; DERA Porton Down, Defence Evaluation and Research Agency, Salisbury, Wiltshire SP4 0JQ (GB). SQUIRRELL, David, James [GB/GB]; DERA Porton Down, Defence Evaluation and Research Agency, Salisbury, Wiltshire SP4 0JQ (GB).</b></p> <p>(74) Agent: <b>BOWDERY, A., O.; D/IPR, Formalities Section (DERA), Poplar 2, MOD Abbey Wood #19, Bristol BS34 8JH (GB).</b></p> </div> <div style="width: 48%;"> <p>(81) Designated States: <b>AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</b></p> <p><b>Published</b></p> <p><i>With international search report.</i></p> <p><i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p> </div> </div>			9801126.5	21 January 1998 (21.01.98)	GB	9816993.1	6 August 1998 (06.08.98)	GB																		
9801126.5	21 January 1998 (21.01.98)	GB																								
9816993.1	6 August 1998 (06.08.98)	GB																								
<p>(54) Title: <b>ANTIBIOTIC SENSITIVITY TESTING</b></p> <p>(57) Abstract</p> <p>The use of an assay for adenylate kinase in an <i>in vitro</i> test for the effect of external conditions on the growth characteristics of bacterial cells. Such tests in particular include tests for the sensitivity of a bacteria to an antibiotic or a biostatic agent, and tests to assess the growth stage and health of the bacteria. Methods of carrying out these tests and kits for effecting them are also described and claimed.</p> <div style="text-align: center; margin-top: 20px;"> <p>Results from a test with a lytic antibiotic</p> <table style="width: 100%; border: none;"> <tr> <td style="width: 25%; border: 1px solid black; padding: 5px; text-align: center;">No additions —</td> <td style="width: 25%; border: 1px solid black; padding: 5px; text-align: center;">Plus antibiotic +</td> <td style="width: 25%; border: 1px solid black; padding: 5px; text-align: center;">No additions —</td> <td style="width: 25%; border: 1px solid black; padding: 5px; text-align: center;">Plus antibiotic —</td> </tr> <tr> <td style="border: 1px solid black; padding: 5px; text-align: center;">Plus phage ++</td> <td style="border: 1px solid black; padding: 5px; text-align: center;">Plus phage and antibiotic +</td> <td style="border: 1px solid black; padding: 5px; text-align: center;">Plus phage ++</td> <td style="border: 1px solid black; padding: 5px; text-align: center;">Plus phage and antibiotic ++</td> </tr> <tr> <td colspan="2" style="text-align: center;"><b>SUSCEPTIBLE</b></td> <td colspan="2" style="text-align: center;"><b>RESISTANT</b></td> </tr> </table>   <p>Results from a test with a non-lytic antibiotic</p> <table style="width: 100%; border: none;"> <tr> <td style="width: 25%; border: 1px solid black; padding: 5px; text-align: center;">No additions —</td> <td style="width: 25%; border: 1px solid black; padding: 5px; text-align: center;">Plus antibiotic —</td> <td style="width: 25%; border: 1px solid black; padding: 5px; text-align: center;">No additions —</td> <td style="width: 25%; border: 1px solid black; padding: 5px; text-align: center;">Plus antibiotic —</td> </tr> <tr> <td style="border: 1px solid black; padding: 5px; text-align: center;">Plus phage ++</td> <td style="border: 1px solid black; padding: 5px; text-align: center;">Plus phage and antibiotic —</td> <td style="border: 1px solid black; padding: 5px; text-align: center;">Plus phage ++</td> <td style="border: 1px solid black; padding: 5px; text-align: center;">Plus phage and antibiotic ++</td> </tr> <tr> <td colspan="2" style="text-align: center;"><b>SUSCEPTIBLE</b></td> <td colspan="2" style="text-align: center;"><b>RESISTANT</b></td> </tr> </table> </div>			No additions —	Plus antibiotic +	No additions —	Plus antibiotic —	Plus phage ++	Plus phage and antibiotic +	Plus phage ++	Plus phage and antibiotic ++	<b>SUSCEPTIBLE</b>		<b>RESISTANT</b>		No additions —	Plus antibiotic —	No additions —	Plus antibiotic —	Plus phage ++	Plus phage and antibiotic —	Plus phage ++	Plus phage and antibiotic ++	<b>SUSCEPTIBLE</b>		<b>RESISTANT</b>	
No additions —	Plus antibiotic +	No additions —	Plus antibiotic —																							
Plus phage ++	Plus phage and antibiotic +	Plus phage ++	Plus phage and antibiotic ++																							
<b>SUSCEPTIBLE</b>		<b>RESISTANT</b>																								
No additions —	Plus antibiotic —	No additions —	Plus antibiotic —																							
Plus phage ++	Plus phage and antibiotic —	Plus phage ++	Plus phage and antibiotic ++																							
<b>SUSCEPTIBLE</b>		<b>RESISTANT</b>																								

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon		Republic of Korea	PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakhstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

### Antibiotic Sensitivity Testing

The present invention relates to a method for testing the growth characteristics of bacteria, in particular to testing for sensitivity to particular antibiotics or biostatic agents, as well as to kits for use in the method.

Bacteria with antibiotic resistance are becoming an increasingly serious problem. The current method for determining the antibiotic resistances of a strain of bacteria is very time consuming. It requires first the isolation of the organism in pure culture. A 'lawn' of the bacteria is then prepared and allowed to grow in the presence of a set of antibiotics. Zones of inhibition of growth around a particular antibiotic show that the bacteria are susceptible (with the size of the zone indicating the degree of susceptibility). Uninhibited growth in the presence of an antibiotic indicates resistance. The process takes at least two days to complete which is far from ideal, particularly in a clinical situation, where the optimum treatment regime of an infected individual may be determined as a result of these tests.

There is a need for a test which allows relatively rapid assessment of antibiotic resistance or susceptibility, for example within a few hours.

Assays for the detection of microorganisms by measurement of adenylate kinase are known for example from International Patent Application Nos. PCT/GB94/00118 and PCT/GB94/01513. Adenylate kinase is an essential enzyme in all living cells which, in the presence of ADP, catalyses the ATP producing reaction shown below.



In this assay, ADP is added as a reagent to the sample under test, preferably in the presence of magnesium ions. ATP produced as a result of the above-mentioned adenylate kinase reaction can then be detected for example using firefly bioluminescence. For this, reagents such as the combination luciferin/luciferase are added to the mixture, generally after a short incubation period, for example of about 5 minutes, and the luminescent signal produced is monitored.

The sensitivity of this assay is limited only by the background level of adenylate kinase and the purity of reagents used. For example, using *E.coli* as a model system, the adenylate kinase activity from fewer than 100 cells was measured in a 5 minute incubation assay as illustrated in Figure 1 hereinafter. In the tests used to generate this Figure, the sample volume was 200 $\mu$ l.

The applicants have found that adenylate kinase can be used as a sensitive marker of biomass and that the above-mentioned assay techniques can be utilised in studies which give much more detailed information regarding the growth characteristics of bacterial cells.

Thus the invention provides the use of an assay for adenylate kinase in an *in vitro* test for the effect of external conditions on the growth characteristics of bacterial cells.

The adenylate kinase assay provides a rapid and sensitive means of investigating many aspects of bacterial growth and inhibition. The sort of external conditions which may be investigated using the invention are various. For example,

the adenylate kinase assay may be used in methods to determine the sensitivity of a particular bacterial strain or mixed culture to particular antibiotic or biostatic reagents, or the methods may be adapted for use in the screening of reagents for antibiotic or biostatic properties. It has also been found that a comparison of the extracellular adenylate kinase content of a cell culture with the total intracellular and extracellular content is indicative of the growth status and health of the cell culture and thus the adenylate kinase assay may be used to assess these features.

The configuration of the test will take into account the nature of the investigations being undertaken, the type of bacterial samples available, the nature of the samples and reagents if any, which are to be tested and in particular whether they have lytic or non-lytic effects on the cells. Various forms of these tests will be described in more detail hereinafter.

In particular however, the invention provides a method for determining the susceptibility of a bacteria to a test material, which method comprises assaying for the adenylate kinase released by lysis of bacteria from a culture containing said reagent and comparing the results with those obtained from a similar adenylate kinase assay which is either of the culture prior to addition of reagent, and/or of lysed bacteria from the same culture at a different point in time and/or of lysed bacteria from a similar culture which does not contain the reagent.

The reagents tested may be known antibiotics or biostatic agents, or they may be novel compounds or reagents not

previously known as antibiotics so that the test forms part of a screening program.

Some reagents, e.g. antibiotics such as  $\beta$ -lactam antibiotics  
5 such as penicillins like ampicillin and amoxycillin, will cause lysis of bacteria in the culture. Where this does not occur however, it may be necessary to lyse the bacteria prior to effecting the assay. This may be done by various techniques as understood in the art, including treatment with  
10 lytic agents as well as physical methods such as subjecting the bacteria to magnetic or electrical fields, or sonication.

Agents producing lysis of bacteria include detergents and enzymes such as bacteriolysin. These are non-specific  
15 however and will liberate AK from all living material present in the sample. This may be suitable where the sample comprises a pure culture. However, where the bacteria under investigation is a component of a mixed culture, other strategies may be adopted. Specific measurements from target  
20 cells in a mixed sample may be achieved for example by: 1) specific capture of the cells of interest to separate them from contaminating organisms followed by non-specific adenylate kinase measurements; 2) use of a method which only lyses the target cells so only the adenylate kinase from these  
25 is measured; or 3) a combination thereof.

Adenylate kinase from the target bacterial cells only (2 above) may be liberated by using a lytic agent which is specific for the particular bacteria under investigation, for  
30 example a bacteriophage which is specific for the target bacteria and which brings about lysis of that bacteria. These bacteriophages are viruses which infect bacteria, causing lysis of the cells and release of intracellular components,

including adenylate kinase, into the external medium. This release generally occurs about 30 to 60 minutes after infection. It has been found that fewer than 500 cells are detectable using this method in an assay taking 40 minutes.

5

Phages can infect target cells equally well in pure or mixed culture. By comparing the amount of adenylate kinase which can be chemically extracted from a sample with the amount released after a set time with phage infection, the presence or absence of target cells can be determined and the effects of the test material on their growth measured.

10

In order for bacteriophage to reproduce and therefore bring about lysis, the host cell must be in the log phase of growth. If growth is inhibited for example, as a result of the presence of a bacteriostatic agent or antibiotic, the bacteriophage will not be able to grow and lyse the cells. This can be used as a basis for a further embodiment of the invention as illustrated below.

15

20

Alternatively or additionally, a mixed culture may be subjected to a pretreatment step wherein the target bacterial cells are either enriched in the culture and/or separated from it. Such steps are well known in the art. For example, separation may be effected using immunocapture techniques where antibodies or binding fragments thereof which are specific for particular bacteria are used to immobilise those cells on a solid surface, such as a beads, microtitre plates, filter membranes or columns. Magnetic beads may provide a particularly preferred solid surface. Separation of the beads, where appropriate using magnetic separation techniques leads to substantial isolation of the target bacteria as

25

30

illustrated hereinafter. It has been found that typically, using magnetic beads as the solid support, detection of fewer than 1000 cells can be achieved with a total assay time of about 30 min. Other materials may also be used as a solid support.

Further specificity may be gained by the use of selective growth media. This can be used in the enrichment step to establish a healthy growing culture, either prior to the immunocapture assay, or infection by a bacteriophage. Additionally, selective media can be used throughout the course of the bacteriophage infection.

Such media will minimise overgrowth by non-target organisms, which may be present, sometimes vastly in excess of the target bacteria.

As mentioned above, the invention may be adapted for use in the testing of bacteria for susceptibility to particular antibiotics or bacteriostatic agents.

Antibiotics such as  $\beta$ -lactams like penicillins work by disrupting cell wall synthesis thereby causing the cells to lose integrity and lyse during replication. This occurs relatively rapidly, about 10-15 minutes after exposure to the antibiotic, provided that the bacteria are actively growing.

Other antibiotics, such as chloramphenicol, do not cause cell lysis but inhibit cell growth in other ways, as do biostatic agents. The mode of action of any particular agent in use is generally understood. The invention may be adapted for use in testing the sensitivity to bacteria to any of these agents.



Specific embodiments of the invention include a method for determining the sensitivity of a bacteria to a lytic antibiotic, said method comprising the steps of (i) separating said bacteria from other microbial species, for example using an immunocapture step; (ii) determining the extracellular adenylate kinase content of a culture of said bacteria (iii) adding the lytic antibiotic to the culture and incubating it for a period sufficient to allow the antibiotic to exert its lytic effect, and (iv) determining the extracellular adenylate kinase content of the culture to assess whether lysis has taken place.

In this test, sensitive bacteria would be lysed by the antibiotic soon after addition thereof, generally within about 15 minutes. Hence the free adenylate kinase content of the culture would increase significantly following addition of the antibiotic as the bacterial cells break open liberating intracellular adenylate kinase. Optimally measurement of the adenylate kinase levels would be taken shortly before antibiotic addition, and then again at least 15 minutes after antibiotic addition. The free adenylate kinase content of cultures of resistant bacteria would remain largely constant. Only the normally present, low level extracellular adenylate kinase content would therefore be measured and, as explained above, this remains approximately steady for healthy growing cells. Using this method, an assessment of antibiotic sensitivity may be achieved in a period of approximately 40 minutes.

The culture of bacteria used in this method may comprise a selective growth medium which favours said bacteria as discussed above as this will minimise any false positive results as a result of contamination.

Alternatively another embodiment of the invention provides a method for determining the sensitivity of a bacteria to a non-lytic antibiotic or biostatic agent, said method comprising

5 (i) separating said bacteria from other microbial species, for example using an immunocapture technique, (ii) incubating a culture of said bacteria in the presence of said non-lytic antibiotic or biostatic agent and optionally a selective growth medium which favours said bacteria, (iii) determining

10 whether the total adenylate kinase content of the culture increases or decreases over the period of the incubation by removing samples at spaced time periods, lysing bacteria in these samples and assaying for adenylate kinase in said samples.

15 In this case, the amount of adenylate kinase obtainable following chemical lysis over a period of time, for example of about an hour, will remain approximately constant if the bacteria are susceptible to the antibiotic. This is because

20 the bacteria are not able to grow in the presence of the antibiotic. In the case of resistant bacteria however, they will continue to grow and so the levels of adenylate kinase will increase steadily with time.

25 Thus, the sensitivity of a pure culture to any particular antibiotic, whether lytic or non-lytic, may be determined rapidly using the methodology of step I above.

Other embodiments of the invention avoid the need for using

30 isolated or pure cultures of bacteria. In particular the invention further provides a method for determining the sensitivity of a bacteria to an antibiotic or biostatic agent, said method comprising

- (a) incubating a first sample of a culture of said bacteria, a second sample in the presence of said antibiotic, a third sample in the presence of a bacteriophage which will specifically lyse said target bacteria and a fourth sample in the presence of both said bacteriophage and said antibiotic;
- 5 (b) determining the adenylate kinase content of each of the first to fourth samples after culture, and
- (c) determining the sensitivity or resistivity of the bacteria on the basis of the adenylate kinase assay results
- 10 and on the mode of action of the antibiotic or biostatic agent.

Since bacteria must be actively growing in order to be susceptible to antibiotic effect, selective media could be used

15 for an initial enrichment step. This may comprise an incubation of about an hour. After this time the target cells may, if desired, be concentrated by immunocapture into fresh selective medium. The effect of adding antibiotics to the target cells could be determined using adenylate kinase

20 measurements in combination with bacteriophage mediated lysis.

In order for a bacteriophage to reproduce, the host cell must be in the log phase of growth. If growth is inhibited, e.g. due to the presence of an antibiotic, then the phage will not

25 be able to replicate and will, therefore, not be able to cause the host cells to be lysed. Using the adenylate kinase assay in conjunction with bacteriophage, the antibiotic sensitivities of bacteria can be determined within 3 hours. The additional time is needed to establish healthy, growing

30 cells prior to exposure to the antibiotic or infection by the phage. Two types of test outcome are possible depending upon the mode of action of the antibiotic concerned.

The results obtained are summarised in Figure 4 where "-" indicates a result which is consistent with the detection of extracellular adenylate kinase only, "+" indicates a moderately positive result consistent with the detection of intra and extracellular adenylate kinase of the existing sample with no growth, and "++" indicates the detection of elevated levels of adenylate kinase consistent with lysis of the growing culture.

10

As is clear from Figure 4, the pattern of the results obtained using this series of tests can allow ready distinction between susceptible and resistant bacteria, provided the mode of action (lytic or non-lytic) of the agent is understood. The different effects are created as a result of the interaction of the various reagents with the bacteria as will be explained in more detail in the Examples given below.

15

It has been found that a comparison of the extracellular adenylate kinase content of a cell culture with the total intracellular and extracellular content is indicative of the growth status and health of the cell culture.

20

Therefore, yet a further embodiment of the invention provides a method of determining the growth phase of a bacterial culture which method comprises

25

- (a) subjecting a first sample of said bacterial culture to a lytic reagent so as to lyse bacterial cells therein,
- (b) assaying for adenylate kinase in said first sample and also in a second sample of said culture which has not been exposed to the lytic agent; and

30

(c) comparing the results obtained from said first and second cultures and assessing the growth stage of the culture.

Healthy, log phase cultures have relatively low extracellular  
5 adenylate kinase levels (about 1% of the total adenylate  
kinase) and that the proportion of extracellular adenylate  
kinase stays relatively constant throughout log phase, and  
increases as the culture approaches stationary phase.

10 Stationary phase cultures may have as much as a third of the  
total adenylate kinase in the culture medium. Therefore, using  
adenylate kinase, the health of cells, as well as their number  
can be rapidly determined.

This method can be used to, for example to confirm that a  
15 particular cell culture is growing well, for example where  
optimum growth is required, for example in fermentation or  
other processes where bacterial products are required.

Alternatively, it may be necessary to confirm cells are  
growing strongly when screening for antibiotic or  
20 bacteriostatic compounds so that false positive results are  
avoided because weak or stationary phase cultures being used  
in the test. Furthermore, it may be used to determine what  
effect environmental factors, such as temperature or culture  
media, have on the growth of any particular culture.

25 In each case, the adenylate kinase content may be assessed by  
removing samples of the culture and carrying out an adenylate  
kinase assay for example as described in International Patent  
Application Nos. PCT/GB94/00118 and PCT/GB94/01513.

30 The invention also provides test kits for effecting the  
methods of the invention. The test kit will contain suitable  
components which would allow the particular assay to be

carried out. For example, for antibiotic sensitivity testing kits may comprise a range of antibiotics, for example in freeze-dried or other preserved states. It may also comprise reagents for extracting adenylate kinase from a sample such as  
5 detergents or other chemical lytic agents as well as reagents necessary for assaying for adenylate kinase, such as luciferin/luciferase etc.. In addition, for use in situations where mixed bacterial cultures are to be tested, the kits may contain suitable bacteriophages, also in  
10 preserved states such as freeze-dried bacteriophages. Additionally, the kits may comprises suitable selective growth media. The reagents may be supplied in a suitable reaction container such as a multi-well plate.

15 The invention will now be particularly described by way of example with reference to the accompanying diagrammatic drawings in which:

Figure 1 is a graph showing the results of experiments to  
20 measure the adenylate kinase activity from *E. coli* cells;

Figure 2: shows the results of magnetic bead immunocapture assays for *Salmonella typhimurium* in a pure culture and in the presence of  $3.5 \times 10^5$  *Bacillus subtilis* var *niger* vegetative  
25 cells; where ■ shows adenylate kinase activity from cells captured by beads; and □ shows adenylate kinase activity from residual cells in sample (i.e. in the left hand graph from uncaptured *Salmonella* cells and in the right hand graph from these plus non-specific cells;..

30 Figure 3 is a graph showing results from an experiment to investigate the time course of phage mediated release of adenylate kinase from a culture of *Escherichia coli* cells;

Figure 4 is a summary diagram of antibiotic test results obtainable using an embodiment of the invention;

- 5 Figure 5 is a diagram showing an assay plate for testing bacterial samples for antibiotic resistance;

Figure 6 shows the effect of Phage 10359 and 50 mg / litre ampicillin with ampicillin-sensitive and resistant cultures of  
10 *E. coli* 10243, in which O represents the results with sensitive *E. coli* 10243 with ampicillin and phage 10359, ∇ represents the results with no lytic agents and □ represents the results with resistant *E. coli* 10243 with ampicillin and phage; and

- 15 Figure 7 shows the effect of chloramphenicol (34 mg/litre) and phage 10359 on cultures of *E. coli* 10243, in which O represents phage only, ∇ represents phage 10359 and chloramphenicol, □ represents chloramphenicol alone and ◇  
20 represents no phage or chloramphenicol.

#### Example 1

##### Comparison of extracellular and total adenylate kinase contents of a culture

- 25 For example, in one embodiment, a sample of bacterial cells is divided into first and second samples. The first sample of bacterial cells is mixed with a solution containing ADP and a detergent in the presence of magnesium ions. This extracts the adenylate kinase from all the cells present in the sample,  
30 thus allowing the ATP generating reaction to occur. The reaction is allowed to proceed for the required time e.g. 5 minutes, after which bioluminescence reagent is added and the

resulting light measured in a luminometer. An assay performed in this way determines the total amount of adenylate kinase in a sample, be it extracellular or intracellular.

- 5 The second sample is subjected to a similar assay but in the absence of detergent so that only extracellular adenylate kinase is measured.

#### Example 2

10 Use of Immunocapture to separate target cells from a mixed suspension.

An immunocapture assay for *Salmonella typhimurium* from a pure sample and from a sample also containing  $3.5 \times 10^5$  *Bacillus subtilis* var *niger* (BG) vegetative cells was carried out.

- 15 Immunocapture assay carried out in a total volume of 300 $\mu$ l. The immunocapture step, onto magnetic microbeads coated with *S. typhimurium* specific antibody, took 10 minutes. The immobilised beads were washed to remove unbound particles, and a non-specific lysis step was carried out to release adenylate  
20 kinase from bound material. This was detected using a 5 minute adenylate kinase assay.

- The results are shown in Figure 2. The graphs show that about 70% of the target cells can be selectively removed from  
25 suspension, and that this is largely unaffected by the presence of contaminating material (the BG cells).

#### Example 3

Use of Phage Mediated Lysis

- 30 The time course of adenylate kinase release from a culture of *Escherichia coli* cells, some of which were infected with *E. coli* specific bacteriophage was studied. 100 $\mu$ l samples (each



containing just 350 cells) were removed at timed intervals from a culture that had been infected with an *E.coli* specific bacteriophage and then assayed for extracellular adenylate kinase activity after 40 minutes. The results are shown in Figure 3 where ○ = infected culture, and ● non-infected control.

It is clear from these results that fewer than 500 cells are detectable using this method.

#### Example 4

##### Antibiotic sensitivity assays:-lytic antibiotic

Sample cells (which may be mixed or pure cultures) are split into 2 fractions and one infected with bacteriophage. Each of these fractions is then further split into 2 fractions with one being exposed to antibiotic and the other left untreated. The relative levels of extracellular adenylate kinase produced in a set time shows the effects of both the antibiotic and bacteriophage on the target cells. Test results achieved in practise are illustrated in Table 1.

The results show both the antibiotic resistance state of the cells and controls to ensure that the test has functioned correctly.

Table 1**Susceptible Bacteria**

<u>(1) No antibiotic, no phage</u> Low extracellular adenylate kinase levels only, (no lysis).	<u>(2) Antibiotic, no phage</u> adenylate kinase released through lysis due to antibiotic.
<u>(3) No antibiotic, plus phage</u> adenylate kinase released through lysis caused by phage.	<u>(4) Antibiotic plus phage</u> adenylate kinase released though lysis due to antibiotic and phage. Levels lower than (3) because of reduced cell growth and inhibition of phage replication.

5

**Resistant Bacteria**

<u>(1) No antibiotic, no phage</u> Low extracellular adenylate kinase levels only, (no lysis).	<u>(2) Antibiotic, no phage</u> Low extracellular adenylate kinase levels only, (no lysis). Same as (1).
<u>(3) No antibiotic, plus phage</u> adenylate kinase released through lysis caused by phage.	<u>(4) Antibiotic plus phage</u> adenylate kinase released through lysis due to phage. Same as (3).

**Example 5**

Antibiotic sensitivity assays:-non-lytic antibiotic or  
biostatic agent

10

The susceptibility of bacteria to antibiotics which do not cause cell lysis, but inhibit cell growth in other ways, (and other chemicals which inhibit bacterial cell growth, such as

biostatic agents) can also be rapidly determined using a similar method.

Sensitivity testing of bacteria in mixed culture to non-lytic antibiotics would be carried out in the same way as testing for susceptibility to antibiotics causing lysis. However, since the bacteria must be actively growing to permit bacteriophage infection, susceptibility to antibiotic would be indicated by a lack of phage mediated lysis in the treated sample.

The results which would be observed are summarised in Table 2.

Table 2

15

**Susceptible Bacteria**

<u>(1) No antibiotic, no phage</u> Low extracellular adenylate kinase levels only, (no lysis).	<u>(2) Antibiotic, no phage</u> Low extracellular adenylate kinase levels only, (no lysis). May be even lower than (1) through inhibition of growth.
<u>(3) No antibiotic, plus phage</u> adenylate kinase released through lysis caused by phage.	<u>(4) Antibiotic plus phage</u> Low extracellular adenylate kinase levels only, (no lysis). May be even lower than (1) through inhibition of growth.

Table 2 contd  
Resistant Bacteria

<u>(1) No antibiotic, no phage</u> Low extracellular adenylate kinase levels only, (no lysis).	<u>(2) Antibiotic, no phage</u> Low extracellular adenylate kinase levels only, (no lysis). Same as (1).
<u>3) No antibiotic, plus phage</u> adenylate kinase released through lysis caused by phage.	<u>4) Antibiotic plus phage</u> adenylate kinase released through lysis due to phage. Same as (3).

5

#### Example 6

#### Test Kit for testing for antibiotic resistance

A suitable test kit comprises a sample container which typically might be a plastic plate in which are formed a number of wells as illustrated in Figure 5. The total volume of liquid that could be held in each well may be approximately 0.5ml. The plates are suitably pre-prepared so that particular wells would contain appropriate freeze-dried (or otherwise preserved) preparations of antibiotics and/or bacteriophages, and optionally also selective growth media.

In a plate such as shown in Figure 5, each row of 4 wells is designed to be used to test for resistance to a particular antibiotic, so using this plate, 3 antibiotics could be tested simultaneously.

In use, about 0.2ml volume of the samples for test, which may be pure cultures, preparations enriched by immunocapture,

samples from selective media or neat samples as appropriate, are added to each well. After incubation at, for example 37°C for 1 hour, reagents to measure the adenylate kinase activity, may be added. These may be reagents which produce a  
5 colorimetric signal in the presence of adenylate kinase, or more preferably, reagents which generate a bioluminescence signal.

In particular ADP and a source of magnesium ions, followed  
10 after 5 minutes by luciferin and luciferase, would be added. The light emission would either be determined 1 well at a time by transfer to tubes and measurement in a tube luminometer, or, preferably, the plate would be assayed automatically in a plate luminometer or be imaged as a whole using a CCD camera  
15 system.

#### Example 7

##### Comparison of the effect of lytic and non-lytic antibiotics on culture growth

20 The effect of lytic (ampicillin) and non-lytic (chloramphenicol) antibiotics on *E. coli* culture growth were examined.

A plasmid encoding ampicillin resistance (pUC18) was  
25 introduced into a pure culture of *E. coli* 10243 in order to induce resistance without altering phage host specificity. The resistant strain was also tested to ensure that carrying the plasmid did not alter its growth rate or infection by phage 10359, and was seen to be the same as the sensitive strain  
30 regarding growth and infection.

The adenylate kinase released from sensitive (untransformed) bacteria and resistant bacteria in the presence of the *E. coli* bacteriophage 10359 and either a lytic (ampicillin) or non-lytic (chloramphenicol) antibiotic were compared.

5

Log phase cultures of both resistant and sensitive strains of *E. coli* 10243 were infected with  $10^5$  phage 10359 at  $T_0$  and 50  $\mu\text{g/ml}$  ampicillin at  $T_5$ . Cell lysis due to ampicillin was evident at  $T_{10}$  and significant at  $T_{20}$  in the sensitive strain, masking any lytic effects due to bacteriophage. The resistant strain was unaffected by the antibiotic but showed lysis due to phage infection after 20 minutes, although this was not significant until  $T_{40}$ . The results are shown in Figure 6. This shows that after only 40 min incubation in the presence of ampicillin and phage, the susceptibility of a culture of *E. coli* 10243 towards ampicillin can be determined.

Log phase cultures of *E. coli* 10243 were incubated in the presence of phage 10359 and / or chloramphenicol (34  $\mu\text{g} / \text{ml}$ ) over a period of 80 min and assayed for adenylate kinase as before. The results are shown in Figure 7.

Greater cell lysis was demonstrated where cultures were incubated with both bacteriophage and chloramphenicol compared with chloramphenicol alone. Although chloramphenicol is not a lytic antibiotic, cells lysis were exhibited over the course of the incubation, probably due to cell death. The degree of phage mediated lysis was considerably less in cultures containing the antibiotic, because the bacteria were not growing well and thus prevented the phage from completing their replication cycle.

Following the results obtained with the ampicillin resistant mutant, it would be expected that a chloramphenicol resistant mutant would behave the same in both the presence and absence of the antibiotic. Therefore, after a 60 min incubation, the  
5 degree of increase in background luminescence would indicate whether or not a culture was susceptible to chloramphenicol.

## Claims

1. The use of an assay for adenylate kinase in an *in vitro* test for the effect of external conditions on the growth characteristics of bacterial cells.  
5
2. The use according to claim 1 wherein the test is for the sensitivity of a bacteria to an antibiotic or biostatic agent.
- 10 3. The use according to claim 1 wherein the test is to assess the growth stage of the bacteria.
4. A method for determining the susceptibility of a bacteria to a reagent, which method comprises assaying for the  
15 adenylate kinase released by lysis of bacteria from a culture containing said reagent and comparing the results with those obtained from a similar adenylate kinase assay which is either of the culture prior to addition of reagent, and/or of lysed bacteria from the same culture at a different point in time  
20 and/or of lysed bacteria from a similar culture which does not contain the reagent.
5. A method according to claim 4 wherein bacteria are lysed using a chemical lytic agent.  
25
6. A method according to claim 4 wherein the lytic agent is specific for a particular bacteria.
7. A method according to claim 6 wherein the lytic agent is  
30 a bacteriophage which infects and lyses a specific bacterial genus, species or strain.



8. A method according to claim 4 wherein bacteria are lysed using an enzyme.

9. A method according to claim 8 wherein the enzyme is bacteriolysin.

10. A method according to claim to any one of claims 3 to 9 wherein the bacteria are first subjected to a separation step to substantially remove any other non-target bacteria in the culture.

11. A method according to claim 10 wherein the separation is carried out using an immunocapture method.

12. A method according to claim 11 wherein the said bacteria are concentrated at a solid surface on which antibodies or the binding fragments thereof which are specific for the target bacteria are immobilized.

13. A method according to any one of claims 4 to 12 wherein the culture further comprises a growth medium which selectively favours the said bacteria.

14. A method according to claim 4 for determining the sensitivity of a bacteria to a lytic antibiotic, said method comprising the steps of (i) separating said bacteria from other microbial species (ii) determining the extracellular adenylate kinase content of a culture of said bacteria (iii) adding the lytic antibiotic to the culture and incubating it for a period sufficient to allow the antibiotic to exert its lytic effect, and (iv) determining the extracellular adenylate kinase content of the culture to assess whether lysis has taken place.

15. A method according to claim 14 wherein in step (i), the bacteria are separated using immunocapture techniques.

5 16. A method according to claim 14 or claim 15 wherein the said culture of bacteria comprises a selective growth medium which favours said bacteria.

10 17. A method according to claim 4 for determining the sensitivity of a bacteria to a non-lytic antibiotic or biostatic agent, said method comprising (i) separating said bacteria from other microbial species, (ii) incubating a culture of said bacteria in the presence of said non-lytic antibiotic or biostatic agent (iii) determining whether the  
15 total adenylate kinase content of the culture increases or decreases over the period of the incubation by removing samples at spaced time periods, lysing bacteria in these samples and assaying for adenylate kinase in said samples.

20 18. A method according to claim 17 wherein the bacteria are lysed using a chemical lytic agent.

19. A method according to claim 17 or claim 18 wherein in step (i), the bacteria are separated using immunocapture  
25 techniques.

20. A method according to any one of claims 17 to 19 wherein the said culture of bacteria comprises a selective growth medium which favours said bacteria.

21. A method for determining the sensisitivity of a bacteria to an antibiotic or biostatic agent, said method comprising

- 5 (a) incubating a first sample of a culture of said bacteria, a second sample in the presence of said antibiotic, a third sample in the presence of a bacteriophage which will specifically lyse said target bacteria and a fourth sample in the presence of both said bacteriophage and said antibiotic;
- 10 (b) determining the adenylate kinase content of each of the first to fourth samples after culture, and
- (c) determining the sensitivity or resistivity of the bacteria on the basis of the adenylate kinase assay results and on the mode of action of the antibiotic or
- 15 biostatic agent.

22. A method according to claim 21 wherein the results obtained in step (c) are compared with the results given in Figure 4 herein to determine whether the bacteria is resistant

20 or susceptible to the antibiotic or biostatic agent.

23. A method according to claim 21 or claim 22 wherein concentration of the said bacteria in the culture is increased prior to step (a) by an immunocapture procedure.

25

24. A method according to any one of claims 21 to 23 wherein the said samples further comprise a selective growth medium which favours growth of said bacteria in preference to other microbial species.

30

25. A method of determining the growth phase of a bacterial culture which method comprises

- 5 (a) subjecting a first sample of said bacterial culture to a lytic reagent so as to lyse bacterial cells therein,
- (b) assaying for adenylate kinase in said first sample,
- (c) assaying for adenylate kinase in a second sample of said culture which has not been exposed to the lytic agent; and
- 10 (c) comparing the results obtained from said first and second cultures and assessing the growth stage of the culture.

26. A method according to claim 25 wherein in step (c), results showing that adenylate kinase levels in the second samples which are of the order of 1% of the levels found in  
15 the first sample is indicative of a healthy, log phase culture and levels in excess of 1% are indicative of a progression into stationary phase.

27. A method according to claim 25 or claim 26 wherein the  
20 lytic agent comprises a detergent or a bacteriophage which specifically infects and lyses particular target bacterial cells.

28. A test kit for testing the sensitivity of bacteria to  
25 antibiotics, said kit comprising one or more antibiotics, and one or more reagents necessary for assaying for adenylate kinase.

29. A test kit according to claim 28 wherein the said  
30 reagents necessary for assaying for adenylate kinase comprise ADP, a source of magnesium ions, luciferin and luciferase.

30. A test kit according to claim 28 or claim 29 wherein the antibiotics are freeze-dried.

31. A test kit according to any one of claims 28 to 30 which  
5 further comprises a lytic agent.

32. A test kit according to claim 31 wherein the lytic agent comprises a chemical agent.

10 33. A test kit according to claim 31 wherein the lytic agent comprises a bacteriophage which is specific for the particular target bacterial cells.

34. A test kit according to any one of claims 28 to 33 which  
15 further comprises a multi-well plate.

35 The use according to claim 1 substantially as, hereinbefore described with reference to the Examples.

20 36. A method according to claim 4 substantially as hereinbefore described with reference to the Examples.

37. A test kit substantially as hereinbefore described with reference to Example 6.

1/4

Fig.1.

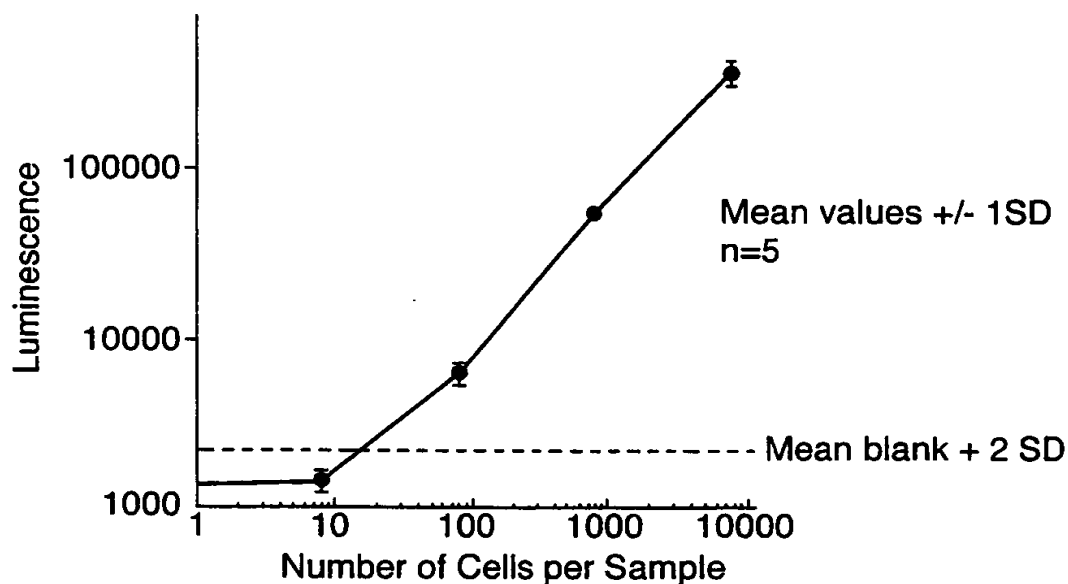
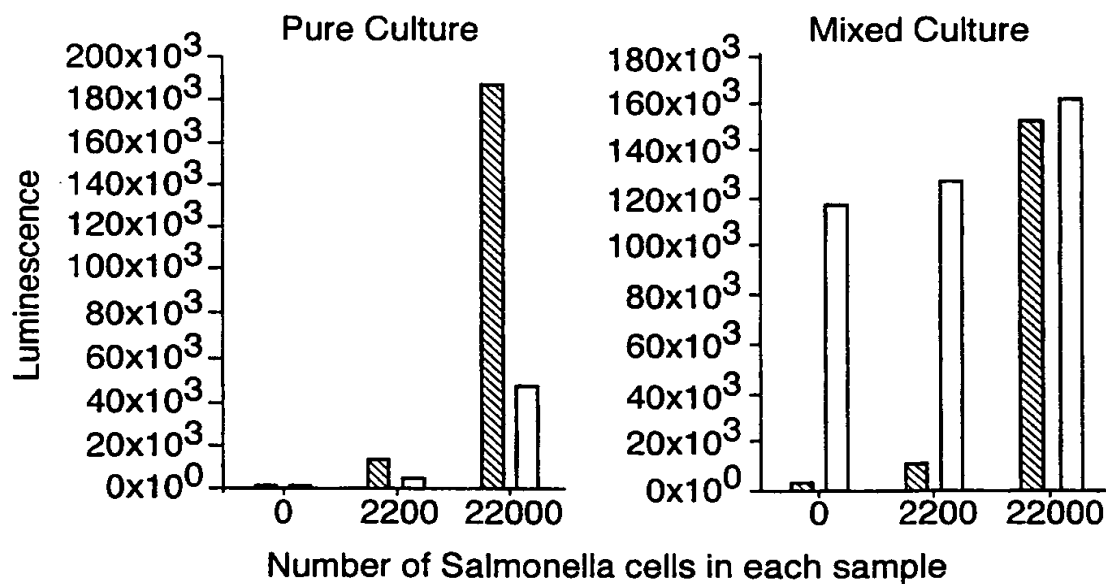


Fig.2.



SUBSTITUTE SHEET (RULE 26)

Fig.3.

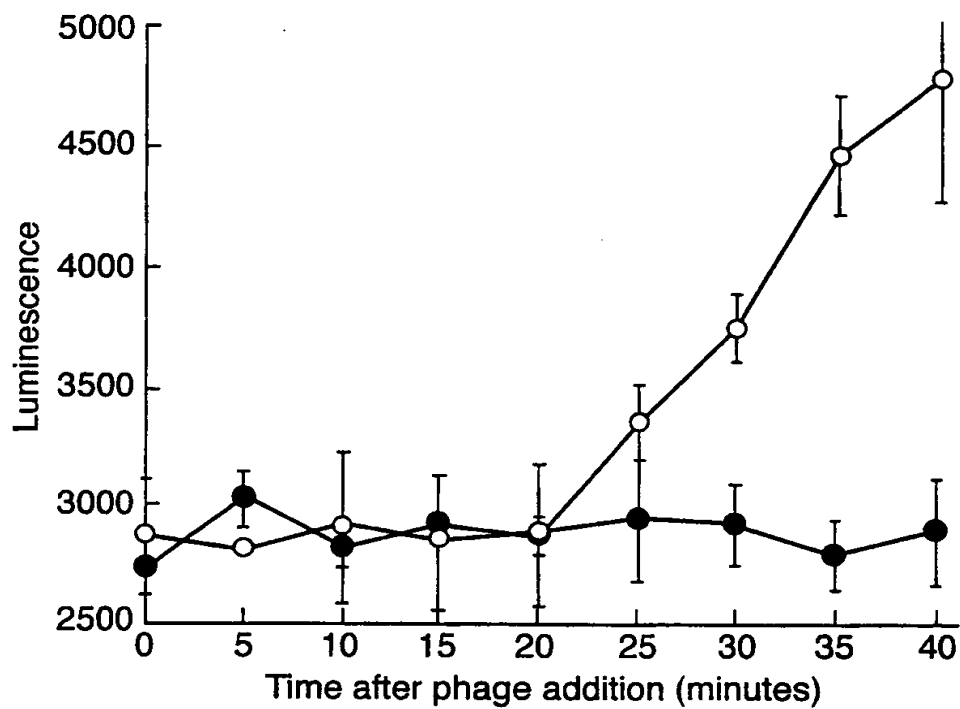


Fig.5.

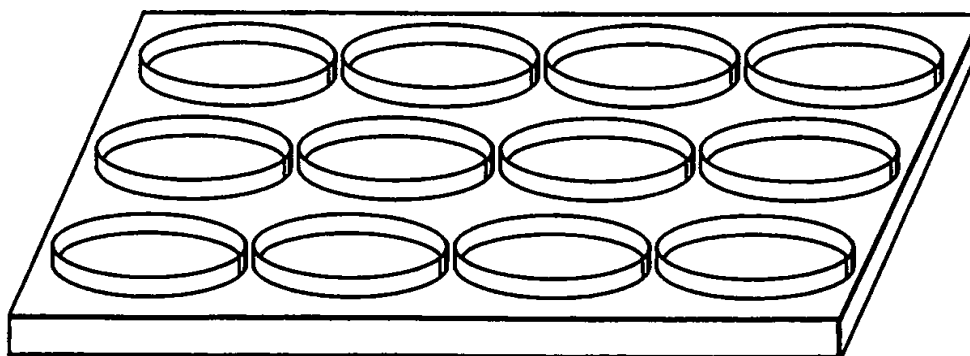


Fig.4.

Results from a test with a lytic antibiotic

No additions —	Plus antibiotic +	No additions —	Plus antibiotic —
Plus phage + +	Plus phage and antibiotic +	Plus phage + +	Plus phage and antibiotic + +
SUSCEPTIBLE		RESISTANT	

Results from a test with a non-lytic antibiotic

No additions —	Plus antibiotic —	No additions —	Plus antibiotic —
Plus phage + +	Plus phage and antibiotic —	Plus phage + +	Plus phage and antibiotic + +
SUSCEPTIBLE		RESISTANT	



4/4

Fig.6.

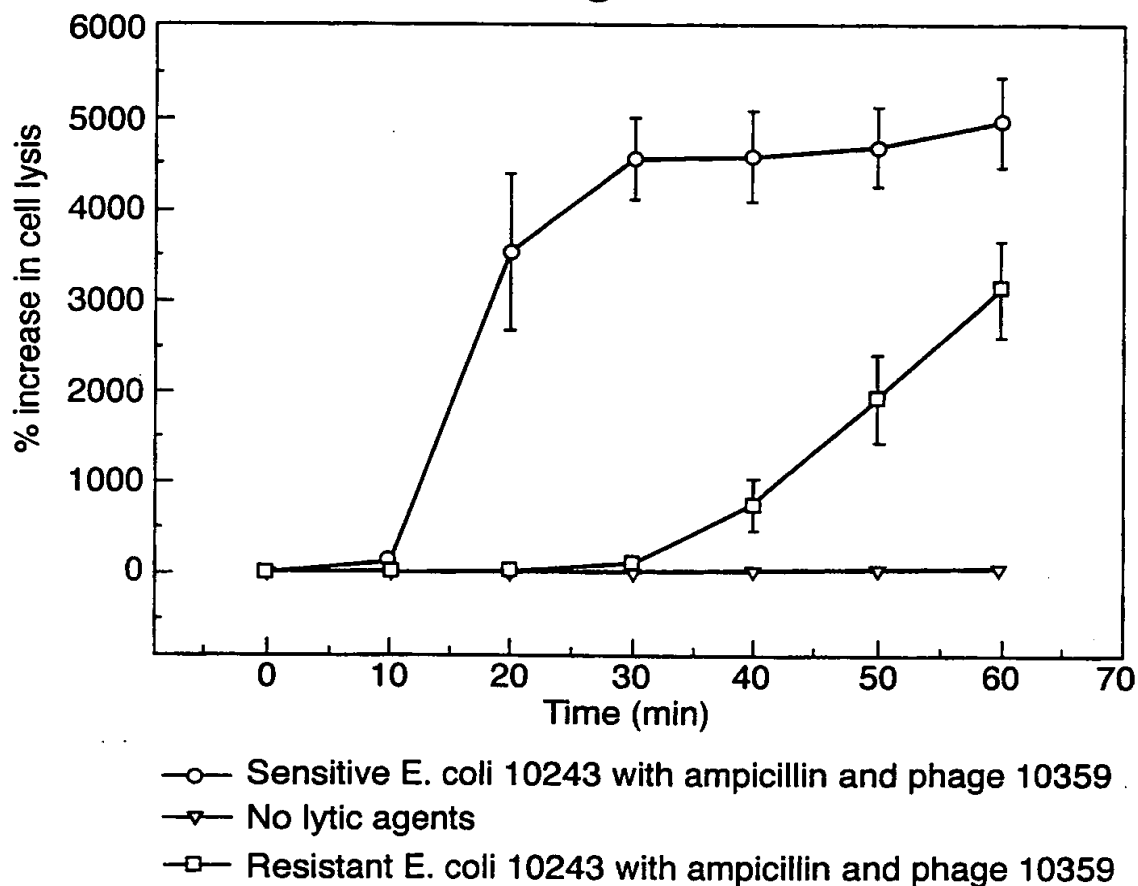
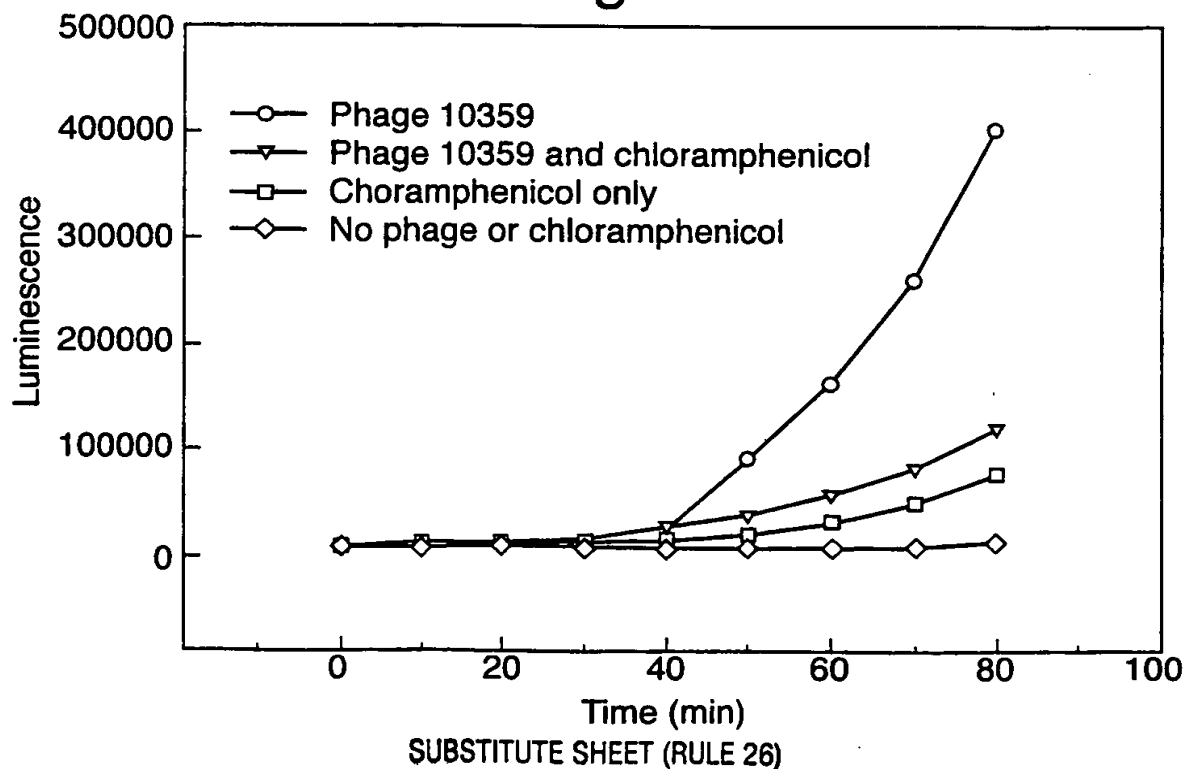


Fig.7.



SUBSTITUTE SHEET (RULE 26)

# INTERNATIONAL SEARCH REPORT

International Application No.

PCT/GB 99/00089

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC 6 C12Q1/18 C12Q1/06 C12Q1/48

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 C12Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 96 02666 A (SECR DEFENCE ; SQUIRRELL DAVID JAMES (GB)) 1 February 1996	1-5, 10-12, 28-32, 34-36
A	see abstract	6-9, 13-27, 33, 37
Y	----- PATENT ABSTRACTS OF JAPAN vol. 017, no. 243 (C-1058), 17 May 1993 & JP 04 370100 A (MERCIAN CORP), 22 December 1992 see abstract	1-5, 10-12, 28-32, 34-36
A	----- WO 94 06931 A (MINI AGRICULTURE & FISHERIES ; SANDERS MICHAEL FREDERICK (GB)) 31 March 1994 see abstract; claims 1,6,7 ----- -/--	1,6

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

\* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

6 May 1999

Date of mailing of the international search report

10/06/1999

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Gundlach, B

## INTERNATIONAL SEARCH REPORT

Int. Patent Application No.

PCT/GB 99/00089

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 96 02665 A (SECR DEFENCE BRIT ;SQUIRRELL DAVID JAMES (GB)) 1 February 1996 cited in the application see abstract see page 3, line 5 - line 18 see claims 1,23-26 ---	1-37
A	WO 94 17202 A (SECR DEFENCE BRIT ;SQUIRRELL DAVID JAMES (GB)) 4 August 1994 cited in the application see abstract ---	1-37
A	SQUIRRELL, D. J. ET AL: "Adenylate kinase as a cell marker in bioluminescent assays" BIOLUMIN. CHEMILUMIN., PROC. INT. SYMP., 8TH (1994), 486-489. EDITOR(S): CAMPBELL, ANDREW KEITH;KRICKA, LARRY J.; STANLEY, PHILIP E. PUBLISHER: WILEY, CHICHESTER, UK. CODEN: 62UZAR, XP002102121 see the whole document ---	1-37
A	MURPHY, M. J. ET AL: "The use of adenylate kinase for the detection and identification of low numbers of microorganisms" BIOLUMIN. CHEMILUMIN., PROC. INT. SYMP., 9TH (1997), MEETING DATE 1996, 319-322. EDITOR(S): HASTINGS, J. W.;KRICKA, L. J.; STANLEY, P. E. PUBLISHER: WILEY, CHICHESTER, UK. CODEN: 65JYAO, XP002102122 see the whole document ---	1-37
P,A	BLASCO, R. ET AL: "Specific assays for bacteria using phage mediated release of adenylate kinase" J. APPL. MICROBIOL. (1998), 84(4), 661-666 CODEN: JAMIFK;ISSN: 1364-5072, April 1998, XP002102123 see the whole document -----	1-37

## INTERN ONAL SEARCH REPORT

information on patent family members

tional Application No

PCT/GB 99/00089

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9602666 A	01-02-1996	AU 691940 B	28-05-1998
		AU 2931995 A	16-02-1996
		BR 9508392 A	26-05-1998
		CA 2194458 A	01-02-1996
		CN 1157638 A	20-08-1997
		EP 0774011 A	21-05-1997
		GB 2304892 A, B	26-03-1997
		HU 76447 A	29-09-1997
		JP 10502815 T	17-03-1998
		NO 970106 A	13-03-1997
		NZ 289464 A	28-07-1998
		US 5798214 A	25-08-1998
		ZA 9505846 A	19-02-1996
WO 9406931 A	31-03-1994	AT 149572 T	15-03-1997
		AU 677223 B	17-04-1997
		AU 4827593 A	12-04-1994
		CA 2144867 A	31-03-1994
		DE 69308581 D	10-04-1997
		DE 69308581 T	26-06-1997
		DK 663016 T	01-09-1997
		EP 0663016 A	19-07-1995
		ES 2098781 T	01-05-1997
		GB 2285684 A, B	19-07-1995
		GR 3023654 T	30-09-1997
		IL 107027 A	14-08-1997
		JP 8503847 T	30-04-1996
		NZ 256076 A	26-01-1996
		US 5888725 A	30-03-1999
		ZA 9306813 A	01-07-1994
WO 9602665 A	01-02-1996	AU 698916 B	12-11-1998
		AU 7130594 A	16-02-1996
		BR 9408598 A	18-11-1997
		EP 0788553 A	13-08-1997
		GB 2303919 A, B	05-03-1997
		JP 10502538 T	10-03-1998
		NO 970105 A	13-03-1997
		NZ 268405 A	19-12-1997
WO 9417202 A	04-08-1994	AT 170222 T	15-09-1998
		AU 677627 B	01-05-1997
		AU 5841794 A	15-08-1994
		BR 9406417 A	26-12-1995
		CA 2154462 A	04-08-1994
		CN 1119029 A	20-03-1996
		DE 69412790 D	01-10-1998
		DE 69412790 T	11-02-1999
		EP 0680515 A	08-11-1995
		ES 2120006 T	16-10-1998
		GB 2289945 A, B	06-12-1995
		HU 72396 A	29-04-1996
		NO 952917 A	06-09-1995
		NZ 259576 A	24-06-1997
		US 5648232 A	15-07-1997